NASA TECHNICAL MEMORANDUM

NASA TM X-64619

SATURN COMPONENT FAILURE RATES AND FAILURE RATE MODIFIERS

Quality and Reliability Assurance Laboratory

N72-13416 (NASA-TM-X-64619) SATURN COMPONENT FAILURE RATE AND FAILURE RATE MODIFIERS (NASA) [1971] 63 p CSCL 14D
Unclas
10421 G3/15

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.
NASA TM X-64619

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE
Saturn Component Failure Rates and Failure Rate Modifiers

5. REPORT DATE

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S) Quality & Reliability Engineering Evaluation Br., Quality & Reliability Engineering Div., Quality & Reliability Assurance Lab.

8. PERFORMING ORGANIZATION REPORT #

9. PERFORMING ORGANIZATION NAME AND ADDRESS
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
National Aeronautics and Space Administration
Washington, D. C. 20546

13. TYPE OF REPORT & PERIOD COVERED
Technical Memorandum

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Prepared by Quality and Reliability Assurance Laboratory, Science and Engineering

16. ABSTRACT
This handbook contains failure mode frequency ratios, environmental adjustment factors, and failure rates for mechanical and electromechanical component families. The failure rates and failure rate modifiers resulted from a series of studies whose purpose was to provide design, test, reliability, and systems engineers with accurate, up-to-date failure rate information. The results of the studies were achieved through (1) an extensive engineering analysis of the Saturn Program test data and Unsatisfactory Condition Reports (UCR's) and (2) the application of mathematical techniques developed for the studies.

17. KEY WORDS

18. DISTRIBUTION STATEMENT
Unclassified--Publicly Available

Wallace E. Jordan

19. SECURITY CLASSIF. (of this report)
Unclassified

20. SECURITY CLASSIF. (of this page)
Unclassified

21. NO. OF PAGES
63

22. PRICE
$3.00

MSFC - Form 3292 (May 1969)

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SATURN COMPONENT FAILURE RATES AND FAILURE RATE MODIFIERS

INTRODUCTION

The purpose of this handbook is to provide design, test, reliability, and systems engineers with up-to-date failure rate information on mechanical and electromechanical components. This document, unlike most others of its kind, provides not only the failure rates for numerous components but also the failure modes, failure mode frequency ratios, and environmental adjustment factors for each type of component.

The information in this handbook is based entirely on data from the Saturn Program. The data were obtained from qualification and reliability test reports and from Unsatisfactory Condition Reports (UCR's) that are associated with components (flight hardware) used in the Saturn Program. The components were analyzed in groups or families to provide better results with the statistical methods employed, and because the amount of data on an individual component was, in many cases, insufficient to permit a meaningful analysis. For the purpose of the analyses and interpretation of the information presented herein, a component family is a grouping of components by functional name. For example, the component family check valve is made up of check valves of various types including poppet spring-loaded valves, ball-seat valves, and flapper-type valves.

The following ground rules were established and followed in generating the information presented herein:

1. Only data on Saturn flight hardware (ground support equipment not included) were used.

2. Data on all components of a given component family were used regardless of part number.

3. Only data from tests involving nonstringent environments, i.e., "bench" tests, were used in the failure rate calculations.

4. It is assumed that the failure mode frequency ratios are constant over the environmental ranges shown.

DESCRIPTION OF VARIABLES AND METHODOLOGY

Failure Rate

The failure rate is the expected number of failures per unit of time or operational cycles. It is based on data from tests conducted in a non-stringent environment, i.e., laboratory environment which is devoid of abnormal vibration, excessive pressure, and high or low temperature. This enables the determination of a meaningful "basic" failure rate which approximates the generic or inherent failure rate for each component family.

The failure rates presented in this handbook are the rates at a 90-percent confidence level. They were calculated using the following formula:

$$\lambda_{90\%} = \frac{\chi^2_{(0.1,\ 2r+2)}}{2T}$$

where $\lambda_{90\%}$ is the failure rate at 90-percent confidence,

$\chi^2_{(0.1,\ 2r+2)}$ is the chi-square value corresponding to 90-percent confidence and $2r + 2$ degrees of freedom,

r is the number of failures, and
T is the total time (total cycles was substituted for total time when a failure rate in terms of failures per cycle was more practical).

Failure Mode Frequency Ratio

The failure mode frequency ratio or alpha factor (α) is the expected proportion of the total failures associated with a component which can be charged to a specific failure mode. In mathematical terms, the alpha factor is the ratio of the failures associated with a specific failure mode to the total number of failures in all modes as shown below:

$$\alpha = \frac{\text{Number of failures in a specific mode}}{\text{Total number of failures in all modes}}$$

This factor is used as a failure rate modifier to assign a certain percentage (α times 100) of the total component failure rate to a particular failure mode. For example, the basic failure rate of the temperature transducer component family is 0.000480 failures per hour and the failure mode frequency ratio associated with the failure mode "open" is 0.55. Therefore, the failure rate of this component family when considering only failures by the mode "open" is 0.000264 failures per hour (0.55 times 0.000480 failures per hour).

The failure modes and failure mode frequency ratios for the component families shown in this handbook were determined through an engineering analysis of the component failures reported on Unsatisfactory Condition Reports (UCR's). Approximately 25 000 UCR's reporting failures on the various stages of the Saturn IB and V vehicles were screened in this analysis.

Environmental Adjustment Factor

An environmental adjustment factor (K factor) is a failure rate modifier. The basic failure rate of a component is multiplied by a K factor corresponding to a given environmental stress level (e.g., an elevated temperature) to determine a failure rate for the component when it is subjected to the given environmental stress level.

The major sources of data for the determination of the environmental adjustment factors were qualification and reliability test reports. The reports were reviewed and the data for such tests as vibration, high and low temperature, and life cycle were extracted. Such variables as time, cycles, number of failures, number of items tested, and test conditions were noted and tabulated on a form specifically designed for this task.

The tabulated data for each set of environmental test conditions were statistically analyzed. The method of analysis involved calculating failure rates at 90-percent confidence for the various environmental levels using the total time and number of failures associated with each level. The following formula was used for this purpose:

$$\lambda_{90\%} = \frac{\chi^2_{(0.1,\ 2r+2)}}{2T}$$

where $\lambda_{90\%}$ is the failure rate at 90-percent confidence,

$\chi^2_{(0.1,\ 2r+2)}$ is the chi-square value corresponding to 90-percent confidence and 2r + 2 degrees of freedom,

r is the number of failures, and

T is the total time (total cycles was substituted for total time when a failure rate in terms of failures per cycle was more practical).

The calculated failure rates and their corresponding environmental variable were then plotted graphically. A line of "best fit" was fitted to the data points using the technique of regression analysis.

Environmental adjustment factors (K) were then determined using (1) the failure rate based on data obtained from testing conducted at ambient conditions, (2) failure rates at various environmental levels taken from the constructed graphs, and (3) the relationship $K = \frac{\text{fail. rate at env. level}}{\text{ambient failure rate}}$. The K values at various levels of the environment were then tabulated, normalized to 1.0 at ambient conditions, and plotted graphically for presentation and engineering use.

To use the graphs it is necessary only to select the environmental level (e.g., temperature) for which a K factor is desired. Next, the selected temperature is found on the horizontal axis and the vertical line representing that temperature is followed until the curve is reached. The horizontal line intersecting the curve and vertical temperature line at the point is then followed to the left margin, where the K value can be found. The K value is used to modify the basic failure rate of a component by multiplying K times the basic failure rate, which results in the component failure rate at the selected temperature. For example, the expected failure rate of a pressure transducer when operated at 200° F is 0.019062 failures per hour, which is the basic failure rate for the pressure transducer component family, 0.009531 failures per hour, times the K factor, 2, corresponding to 200° F.

COMPONENT FAILURE INFORMATION

This section contains the failure rates, failure modes, failure mode frequency ratios, and environmental adjustment factors for various Saturn component families. Spin-off information such as cause of failure and component deficiencies is also presented since it provides valuable facts to be considered in the application and the analysis of the components.

The information in this section is presented alphabetically according to the generic name of the component, e.g., transducer, pressure; valve, check.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Accelerometers

I. Failure Mode Frequency Ratios (α): 1

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}}$$

Failure Mode	Alpha Factor (α)
Erratic Output	0.293
High Output	0.257
Low Output	0.239
No Output	0.211

II. Environmental Adjustment Factors (K): 2

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}}.$$

Figure 1 shows the accelerometer failure rate adjustment factor (K_T) for temperature.

III. Failure rate at 90-Percent Confidence ($\lambda_{90\%}$): 2

$\lambda_{90\%}$ = 0.000560 failures per hour. 3

1 Based on 109 accelerometer failures extracted from 25 000 Saturn UCR's.

2 Based on Saturn test data from 27 qualification and reliability test reports.

3 Based on 3 failures in 11 925 operational hours in tests at ambient conditions.

NOTE: Approximately 4 percent of the accelerometer failures reported on UCR's were associated with contamination which appeared as damping fluid and foreign materials such as microscopic metallic particles.

Approximately 27 percent of the accelerometer failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures were manifested as bent and broken pins, pinched leads, broken plugs and connectors, broken insulation and shields, poor solder connectors, and reversed polarity.

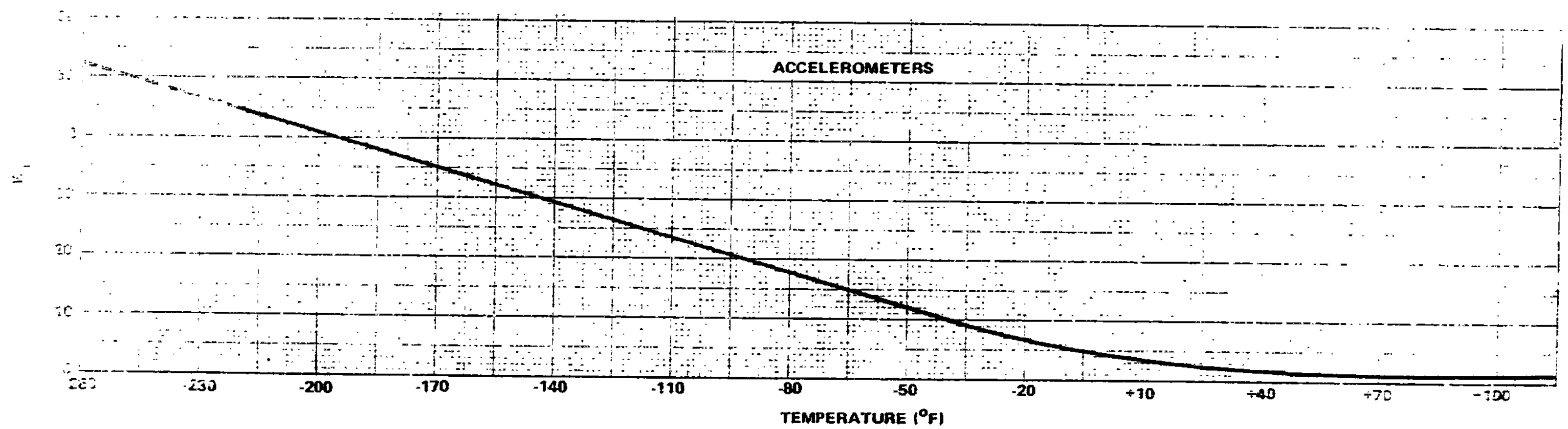

Figure 1. Accelerometer failure rate adjustment factor (K_T) for temperature.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Accumulators

I. Failure Mode Frequency Ratios (α): 1

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}}$$

Failure Mode	Alpha Factor (α)
External Leakage	0.608
Internal Leakage	0.392

II. Environmental Adjustment Factors (K): 2

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}}$$

Figure 2 shows the accumulator failure rate adjustment factor (K_T) for temperature.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): 2

$\lambda_{90\%}$ = 0.0014 failures per hour. 3

1 Based on 23 accumulator failures extracted from 25 000 Saturn UCR's.

2 Based on Saturn test data from 19 qualification and reliability test reports.

3 Based on no failures in 1612 operational hours in tests at ambient conditions.

NOTE: Approximately 8 percent of the accumulator failures reported on UCR's were associated with contamination which appeared as minute foreign particles.

Approximately 31 percent of the accumulator failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures were manifested as cracked and split seals, spiralled, fractured and split O-rings, and a broken accumulator charging valve stem.

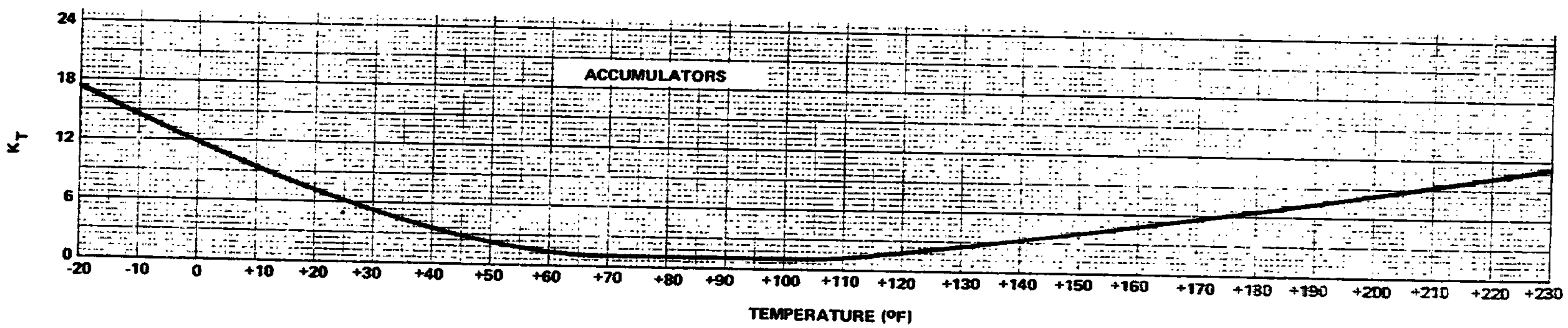

Figure 2. Accumulator failure rate adjustment factor (K_T) for temperature.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Hydraulic And Pneumatic Actuators

I. Failure Mode Frequency Ratios (α): 1

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}}$$

Failure Mode	Alpha Factor (α)
External Leakage	0.470
Failure to Give Proper Position Indication Signal	0.376
Failure to Achieve Correct Position	0.135
Internal Leakage	0.019

II. Environmental Adjustment Factor (K): An environmental adjustment factor for temperature and for vibration could not be calculated because of a lack of sufficient data for other than the ambient-temperature test environment.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): 2

$\lambda_{90\%}$ = 0.0000522 failures per hour. 3

1 Based on 104 hydraulic and pneumatic actuator failures extracted from 25 000 Saturn UCR's.

2 Based on Saturn test data from 54 qualification and reliability test reports.

3 Based on two failures in 101 774 operational hours in tests at ambient conditions.

NOTE: Approximately 7 percent of the hydraulic and pneumatic actuator failures reported on UCR's were associated with contamination which was evidenced by the presence of silt particles, sawdust, paint, and moisture.

Approximately 35 percent of the hydraulic and pneumatic actuator failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures appeared as nicks, gouges, cuts, scratches and dents.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Electrical Connectors

I. Failure Mode Frequency Ratios (α): 1

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}}$$

Failure Mode	Alpha Factor (α)
Loss of Continuity	0.648
Electrical Short	0.099
Fluctuating Resistance	0.099
Improper Fit	0.077
Low Output	0.077

II. Environmental Adjustment Factors (K_E): 2

$$K_E = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}}$$

Figure 3 shows the electrical connector failure rate adjustment factor (K_T) for temperature. Figure 4 shows the electrical connector failure rate adjustment factor (K_V) for vibration.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): 2

$\lambda_{90\%} = 0.001422$ failures per hour. 3

1 Based on 91 electrical connector failures extracted from 25 000 Saturn UCR's.

2 Based on Saturn test data from 36 qualification and reliability test reports.

3 Based on 2 failures in 3744 operational hours in tests at ambient conditions.

NOTE: Approximately 7 percent of the electrical connector failures reported on UCR's were associated with contamination which appeared as corrosion, potting compound, and moisture.

Approximately 63 percent of the electrical connector failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures were manifested as cuts, tears, and scratches.

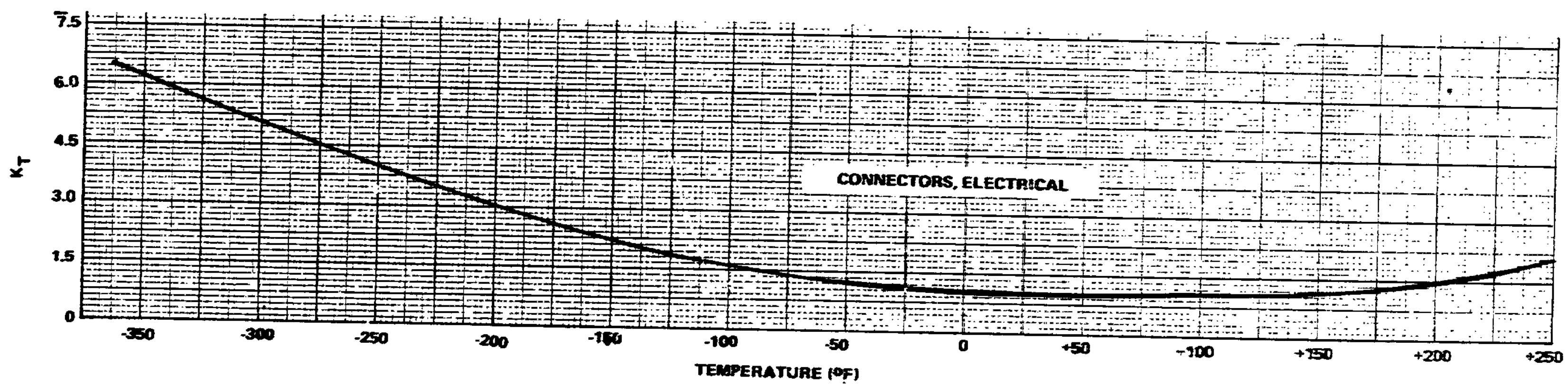

Figure 3. Electrical connector failure rate adjustment factor (K_T) for temperature.

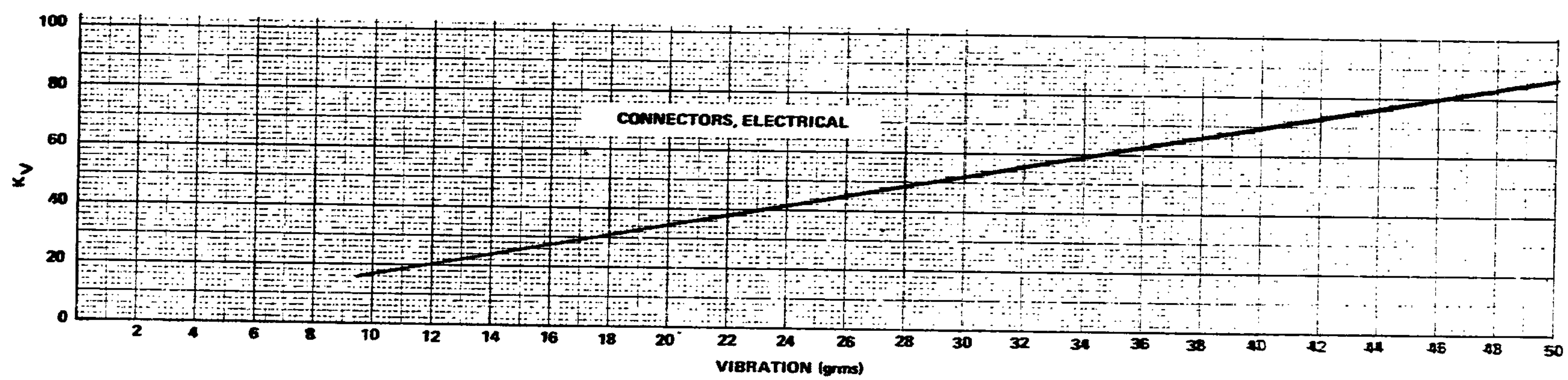

Figure 4. Electrical connector failure rate adjustment factor (K_V) for vibration.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Quick Disconnects

I. Failure Mode Frequency Ratios (α): 1

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}} .$$

Failure Mode	Alpha Factor (α)
Failure to Contain Fluid	0.537
Failure to Check Flow	0.407
Failure to Connect	0.042
Failure to Disconnect	0.014

II. Environmental Adjustment Factors (K): 2

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}} .$$

Figure 5 shows the quick disconnect failure rate adjustment factor (K_T) for temperature.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): 2

$\lambda_{90\%}$ = 0.000790 failures per hour. 3

1 Based on 69 quick disconnect failures extracted from 25 000 Saturn UCR's.

2 Based on Saturn test data from 99 qualification and reliability test reports.

3 Based on one failure in 4924 operational hours in tests at ambient conditions.

NOTE: Approximately 29 percent of the quick disconnect failures reported on UCR's were associated with contamination which was evidenced by the presence of dust, walnut shell grit, corrosion, and paint chips.

Approximately 25 percent of the quick disconnect failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures appeared as scratches, cuts, gouges, and cracks.

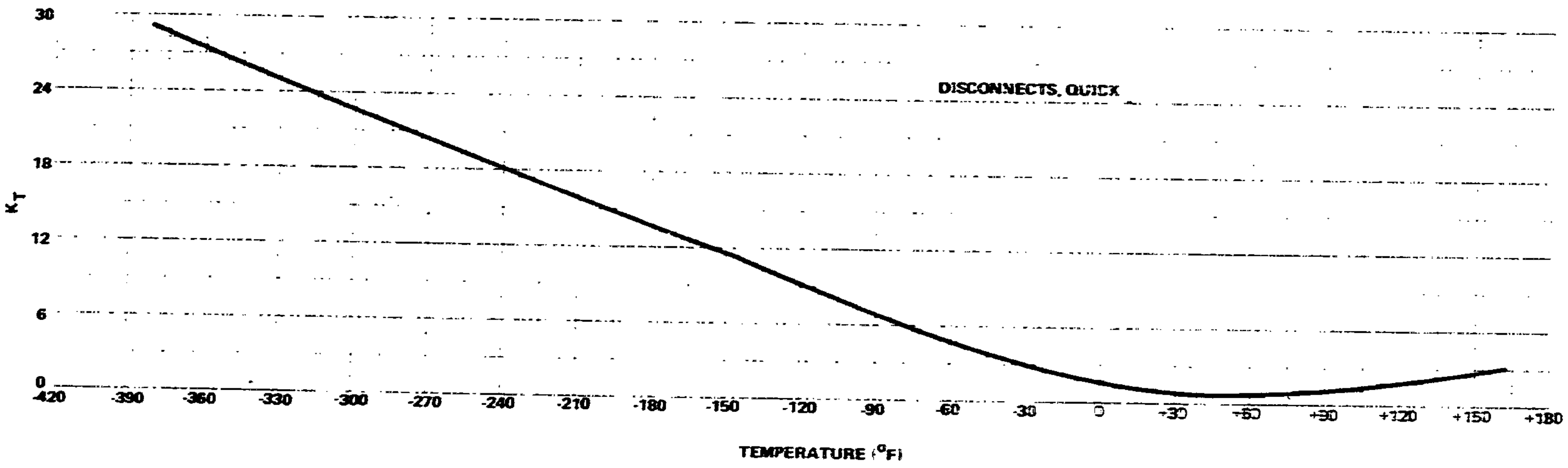

Figure 5. Quick disconnect failure rate adjustment factor (K_T) for temperature.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Mechanical Filters

I. Failure Mode Frequency Ratios (α): [1]

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}} .$$

Failure Mode	Alpha Factor (α)
External Leakage	0.631
Low Flow Rate	0.369

II. Environmental Adjustment Factors (K_E): [2]

$$K_E = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}} .$$

Figure 6 shows the mechanical filter failure rate adjustment factor (K_T) for temperature.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): [2]

$\lambda_{90\%} = 0.000936$ failures per hour. [3]

[1] Based on 19 mechanical filter failures extracted from 25 000 Saturn UCR's.

[2] Based on Saturn test data from 64 qualification and reliability test reports.

[3] Based on 3 failures in 7119 operational hours in tests at ambient conditions.

NOTE: Approximately 23 percent of the mechanical filter failures reported on UCR's were associated with contamination which appeared as seal material, metal filings, and other foreign matter.

Approximately 29 percent of the mechanical filter failures reported on UCR's were damage-type failures, attributable in most cases to human error. The damage-type failures were manifested as cuts, abrasions, depressions, and bends.

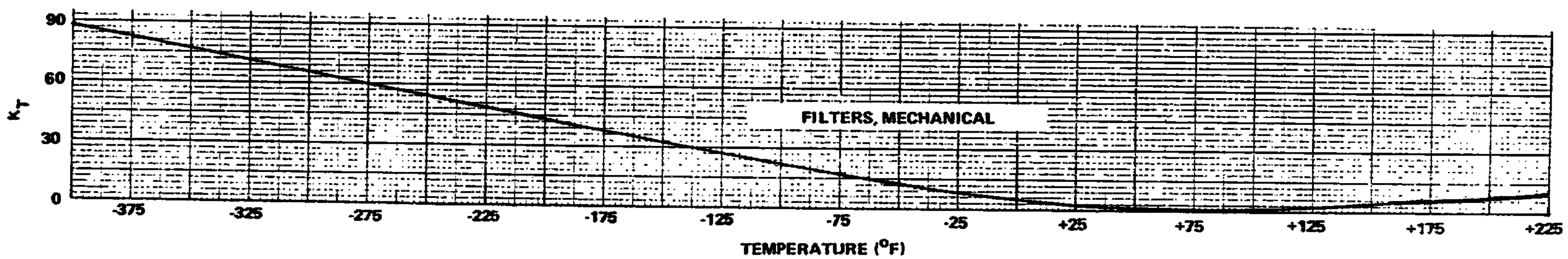

Figure 6. Mechanical filter failure rate adjustment factor (K_T) for temperature.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Pumps

I. Failure Mode Frequency Ratios (α): [1]

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}}$$

Failure Mode	Alpha Factor (α)
External Leakage	0.469
Improper Output	0.297
Failure to Operate	0.157
Improper Pump Output Signal	0.070
Internal Leakage	0.007

II. Environmental Adjustment Factors (K): [2]

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}}$$

Figure 7 shows the pump failure rate adjustment factor (K_T) for temperature, and Figure 8 shows the pump failure rate adjustment factor (K_V) for vibration.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): [2]

$\lambda_{90\%}$ = 0.000398 failures per hour. [3]

[1] Based on 115 pump failures extracted from 25 000 Saturn UCR's.
[2] Based on Saturn test data from 61 qualification and reliability test reports.
[3] Based on 4 failures in 20 060 operational hours in tests at ambient conditions.

NOTE: Approximately 15 percent of the pump failures reported on UCR's were associated with contamination which appeared as walnut shell grit, rust particles, metal slivers, and moisture.

Approximately 18 percent of the pump failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures were manifested as gouges, nicks, dents, and scratches.

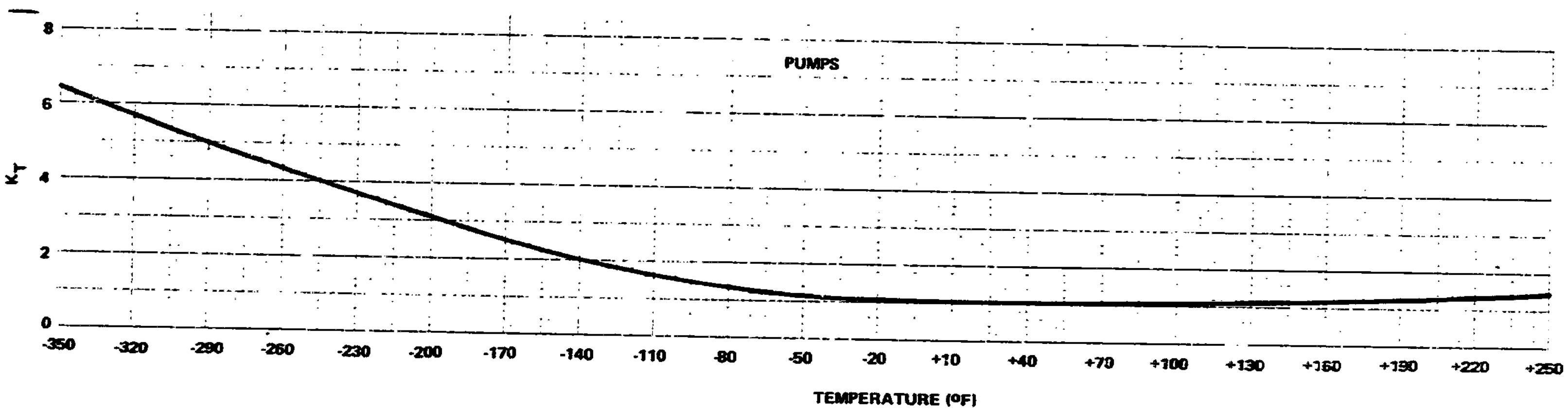

Figure 7. Pump failure rate adjustment factor (K_T) for temperature.

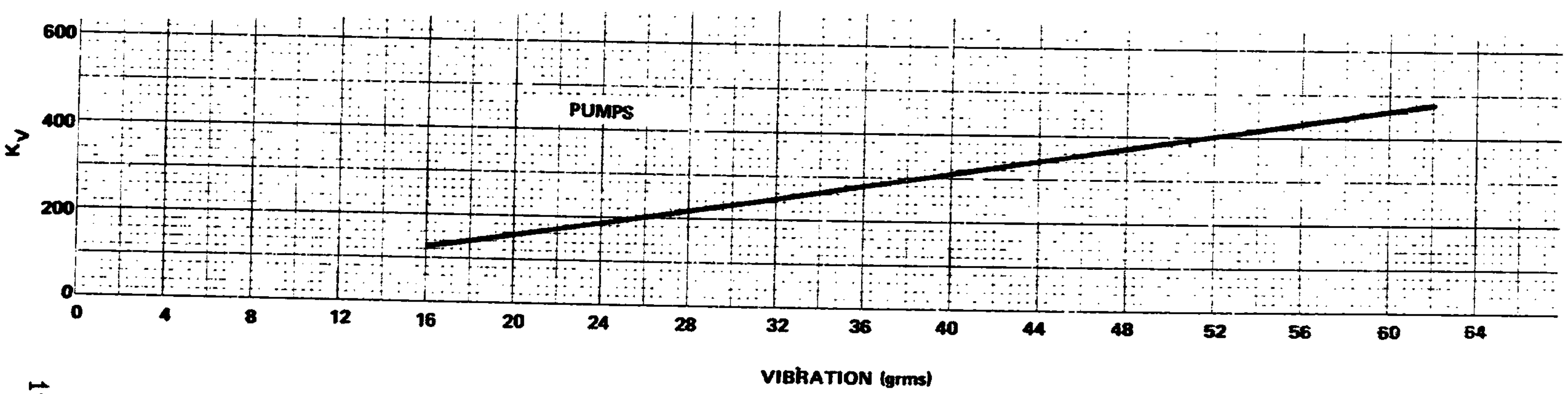

Figure 8. Pump failure rate adjustment factor (K_V) for vibration.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Pressure Regulators

I. Failure Mode Frequency Ratios (α): [1]

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}} .$$

Failure Mode	Alpha Factor (α)
Regulates High	0.672
Regulates Low	0.250
External Leakage	0.078

II. Environmental Adjustment Factors (K): [2]

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}} .$$

Figure 9 shows the pressure regulator failure rate adjustment factor (K_T) for temperature, and Figure 10 shows the pressure regulator failure rate adjustment factor (K_V) for vibration.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): [2]

$\lambda_{90\%} = 0.001000$ failures per hour. [3]

[1] Based on 64 pressure regulator failures extracted from 25 000 Saturn UCR's.

[2] Based on Saturn test data from 64 qualification and reliability test reports.

[3] Based on no failures in 2301 operational hours in tests at ambient conditions.

NOTE: Approximately 23 percent of the pressure regulator failures reported on UCR's were associated with contamination which was evidenced by the presence of lubricants, corrosion, metallic particles, and moisture.

Approximately 16 percent of the pressure regulator failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures appeared as bent connector pins, broken flanges, and nicks, scratches, and gouges on poppets, seats, pistons, and other regulator components.

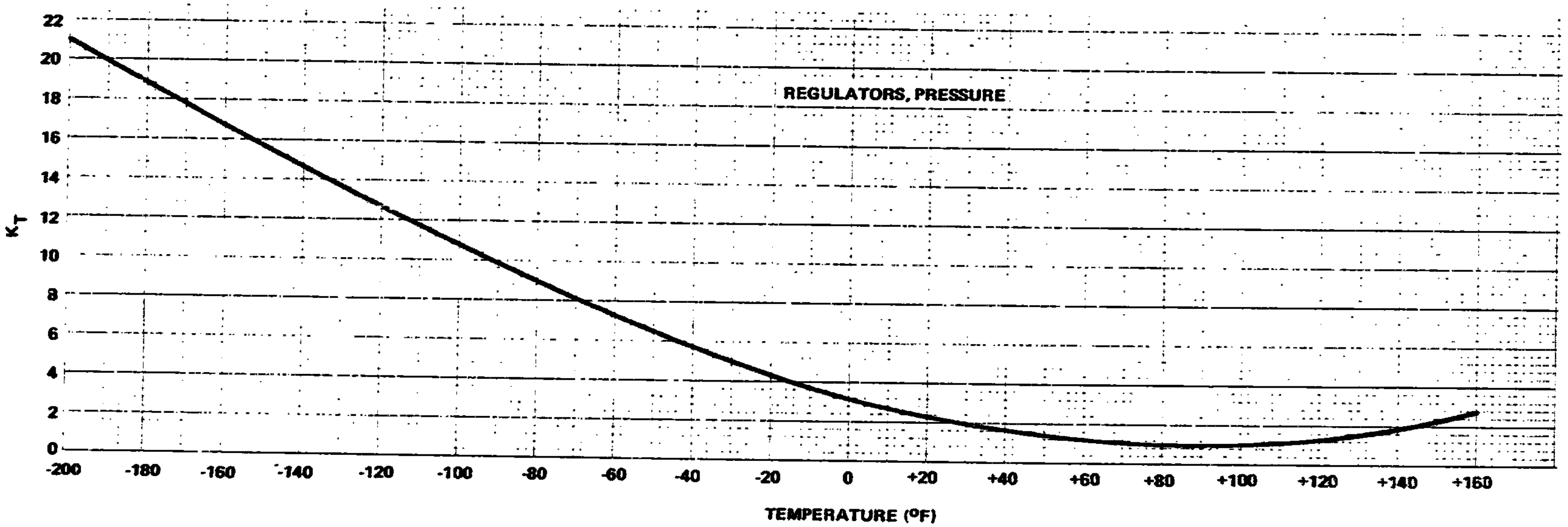

Figure 9. Pressure regulator failure rate adjustment factor (K_T) for temperature.

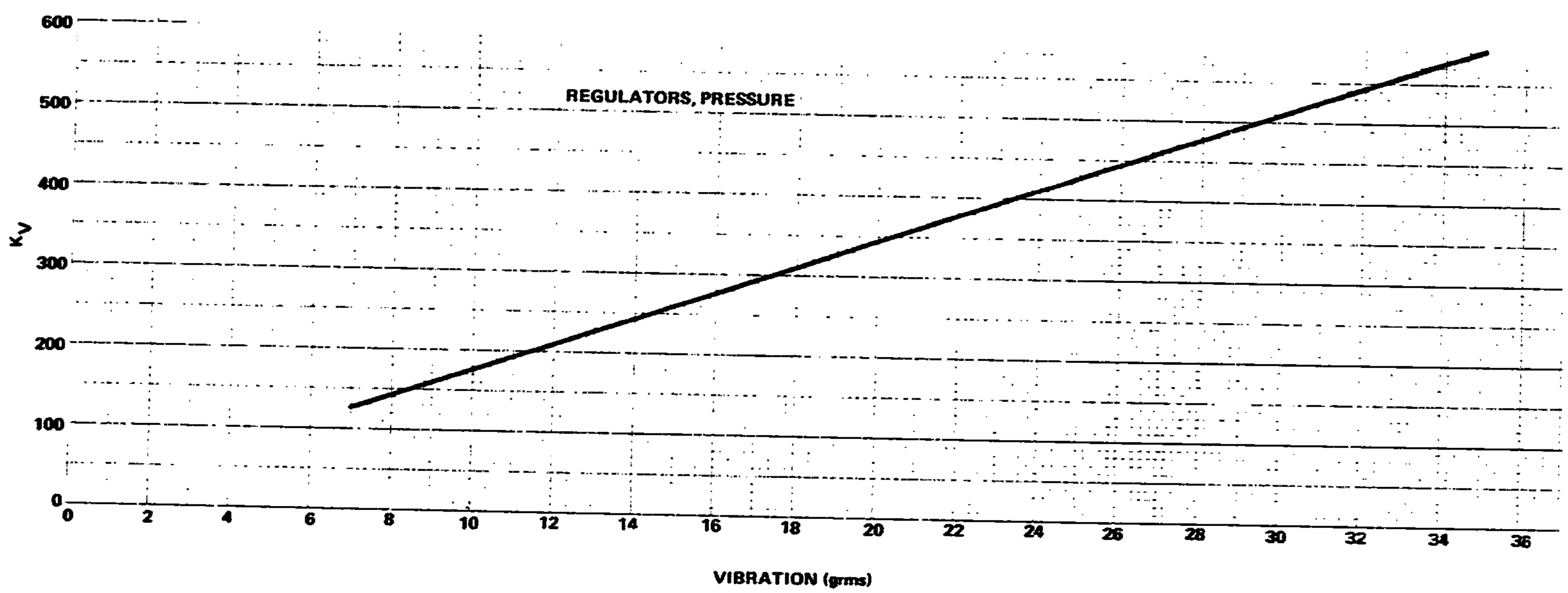

Figure 10. Pressure regulator failure rate adjustment factor (K_V) for vibration.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Electrical Relays

I. Failure Mode Frequency Ratios (α): 1

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}} .$$

Failure Mode	Alpha Factor (α)
Intermittent Operation (contact chatter)	0.56
Failure to Operate (no response, failure to open, failure to close)	0.24
Improper Response (premature contact actuation or deactuation, delayed contact response)	0.20

II. Environmental Adjustment Factors (K_E): 2

$$K_E = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}} .$$

Figure 11 shows the electrical relay failure rate adjustment factor (K_T) for temperature.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): 2

$\lambda_{90\%}$ = 0.000014 failures per hour. 3

1 Based on 91 electrical relay failures extracted from 25 000 Saturn UCR's and 142 component test reports.

2 Based on Saturn test data from 142 qualification and reliability test reports.

3 Based on 51 failures in 4 166 106 operational hours in tests at ambient conditions.

NOTE: Approximately 3 percent of the electrical relay failures reported on UCR's were associated with contamination which appeared as foreign material on electrical contacts. Approximately 8 percent of the electrical relay failures reported on UCR's were damage-type failures, attributable in most cases to human error. The damage-type failures were manifested as abrasions, dents and cuts. Approximately 40 percent of the electrical relay failures occurred during contact bounce tests. The cause of these failures was not stated.

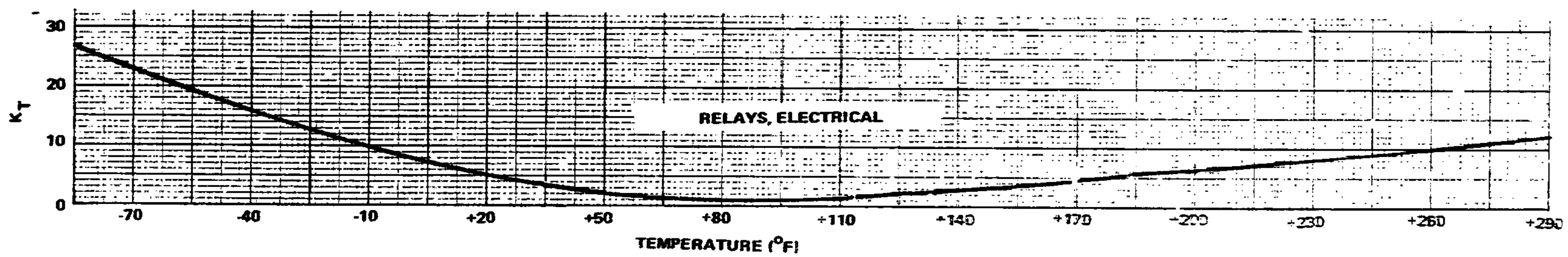

Figure 11. Electrical relay failure rate adjustment factor (K_T) for temperature.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Liquid Level Sensors

I. Failure Mode Frequency Ratios (α): 1

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}} .$$

Failure Mode	Alpha Factor (α)
Incorrect Output	0.679
No Output	0.302
Premature Indication	0.019

II. Environmental Adjustment Factors (K): 2

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}} .$$

Figure 12 shows the liquid level sensor failure rate adjustment factor (K_T) for temperature.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): 2

$\lambda_{90\%} =$ 0.000840 failures per hour. 3

1 Based on 53 liquid level sensor failures extracted from 25 000 Saturn UCR's.

2 Based on Saturn test data from 25 qualification and reliability test reports.

3 Based on 7 failures in 14 601 operational hours in tests at ambient conditions.

NOTE: Approximately 7 percent of the liquid level sensor failures reported on UCR's were associated with contamination which appeared as moisture and foreign particles.

Approximately 41 percent of the liquid level sensor failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures were manifested as gouges, nicks, dents, scratches, and breakage.

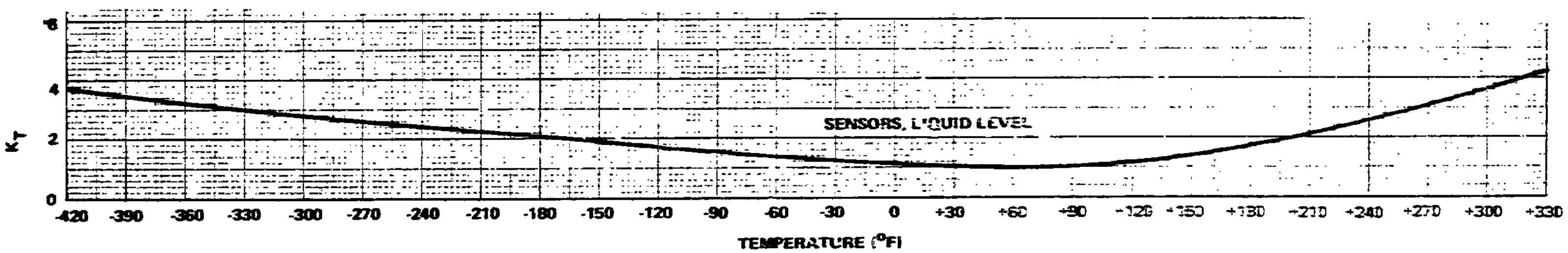

Figure 12. Liquid level sensor failure rate adjustment factor (K_T) for temperature.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Electrical Switches

I. Failure Mode Frequency Ratios (α): ▷1

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}} .$$

Failure Mode	Alpha Factor (α)
Erroneous Output	0.51
Failure to Operate	0.49

II. Environmental Adjustment Factors (K_E): ▷2

$$K_E = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}} .$$

Figure 13 shows the electrical switch failure rate adjustment factor (K_T) for temperature. Figure 14 shows the electrical switch failure rate adjustment factor (K_V) for vibration.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): ▷2

$\lambda_{90\%} = 0.001092$ failures per hour. ▷3

▷1 Based on 53 electrical switch failures extracted from 25 000 Saturn UCR's and 136 component test reports.

▷2 Based on Saturn test data from 136 qualification and reliability tests reports.

▷3 Based on 52 failures in 57 250 operational hours in tests at ambient conditions.

NOTE: Approximately 5 percent of the electrical switch failures reported on UCR's were associated with contamination which appeared as corrosion, metallic particles, and other foreign matter.

Approximately 13 percent of the electrical switch failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures were manifested as scratches, abrasions, and bent or broken parts.

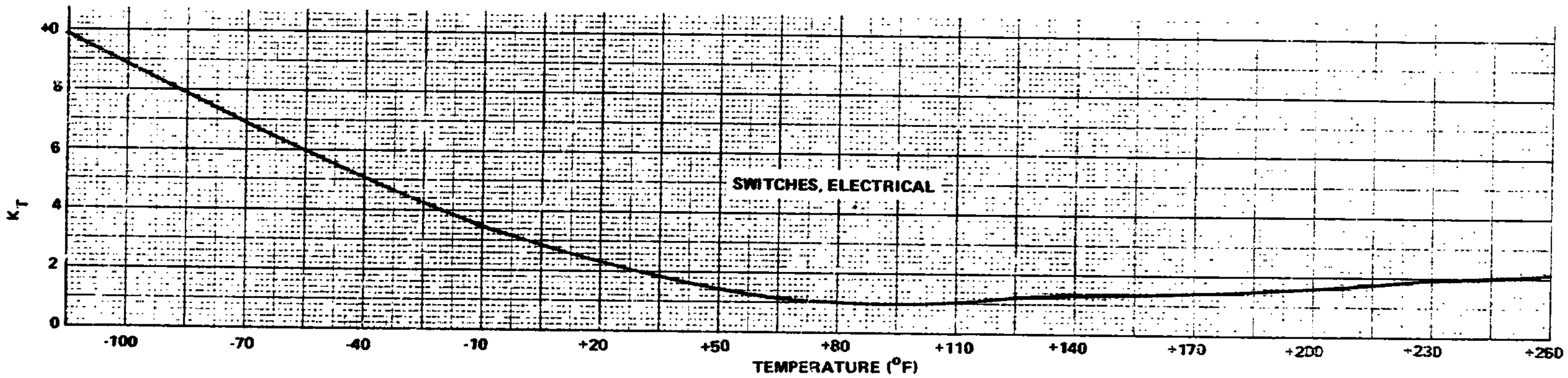

Figure 13. Electrical switch failure rate adjustment factor (K_T) for temperature.

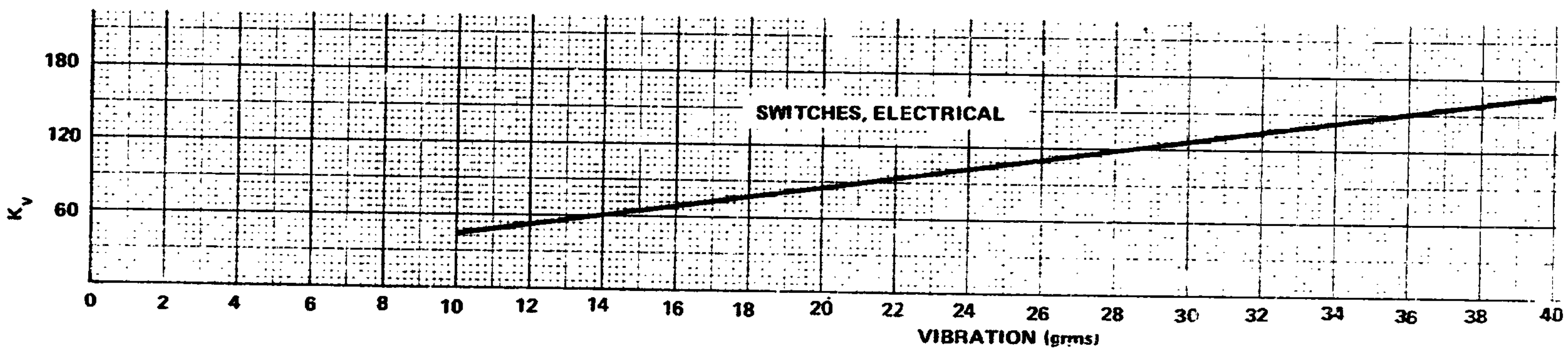

Figure 14. Electrical switch failure rate adjustment factor (K_V) for vibration.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Pressure Switches

I. Failure Mode Frequency Ratios (α): [1]

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}}$$

Failure Mode	Alpha Factor (α)
Failure to Actuate	0.635
Premature Actuation	0.129
Failure to Deactuate	0.118
External Leakage	0.086
Premature Deactuation	0.032

II. Environmental Adjustment Factors (K): [2]

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}}$$

Figure 15 shows the pressure switch failure rate adjustment factor (K_T) for temperature, and Figure 16 shows the pressure switch failure rate adjustment factor (K_V) for vibration.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): [2]

$\lambda_{90\%}$ = 0.000022 failures per cycle. [3]

[1] Based on 93 pressure switch failures extracted from 25 000 Saturn UCR's.

[2] Based on Saturn test data from 63 qualification and reliability test reports.

[3] Based on 1 failure in 177 950 operational cycles in tests at ambient conditions.

NOTE: Approximately 18 percent of the pressure switch failures reported on UCR's were associated with contamination which appeared as corrosion, sand, solder balls, metal slivers, and moisture.

Approximately 16 percent of the pressure switch failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures were manifested as dents, bent connector pins, and damaged diaphragms.

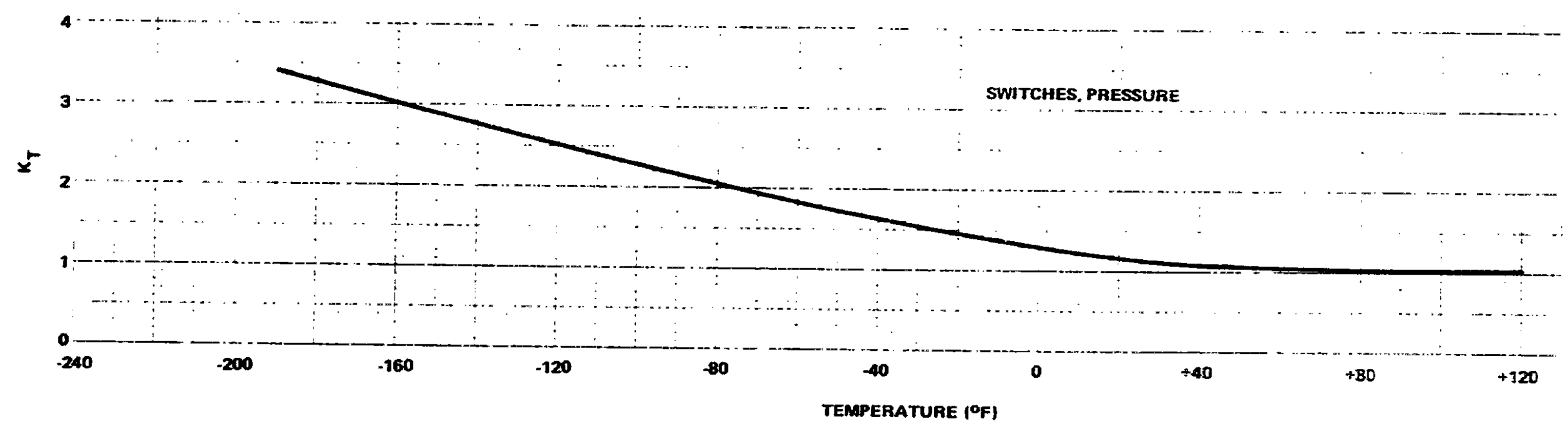

Figure 15. Pressure switch failure rate adjustment factor (K_T) for temperature.

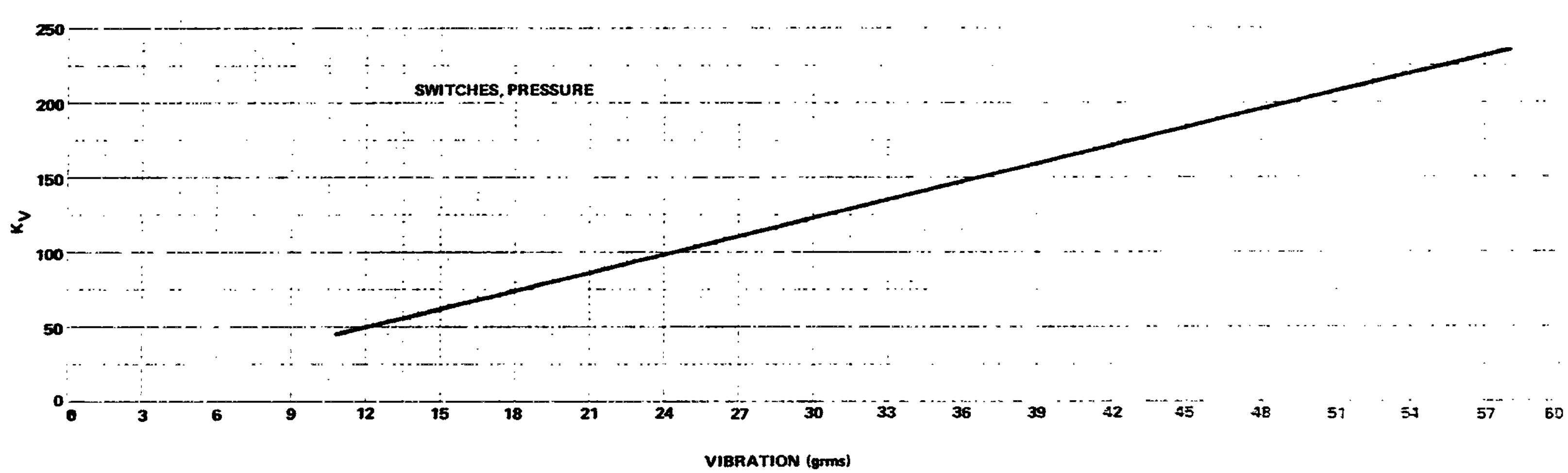

Figure 16. Pressure switch failure rate adjustment factor (K_V) for vibration.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Pressure Transducers

I. Failure Mode Frequency Ratios (α): 1

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}}$$

Failure Mode		Alpha Factor (α)
Low Output Voltage		0.371
a) Below Tolerance	0.218	
b) No Output	0.153	
High Output Voltage		0.333
Erratic Output Voltage		0.265
Leakage		0.031

II. Environmental Adjustment Factors (K): 2

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}}$$

Figure 17 shows the pressure transducer failure rate adjustment factor (K_T) for temperature.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): 2

$\lambda_{90\%} =$ 0.009531 failure per hour. 3

1 Based on 615 pressure transducer failures extracted from 25 000 Saturn UCR's.

2 Based on Saturn test data from 47 qualification and reliability test reports.

3 Based on 6 failures in 1105 hours of operation in tests at ambient conditions.

NOTE: Approximately 18 percent of the 938 pressure transducer failures extracted from UCR's were damage-type failures, caused in most instances by human error. The most prevalent of the damage-type failures were damaged pins, damaged insulation, and damaged seals.

Approximately 4 percent of the failures were caused by contamination in the form of metal particles, walnut grit dust, moisture, and undeterminable deposits.

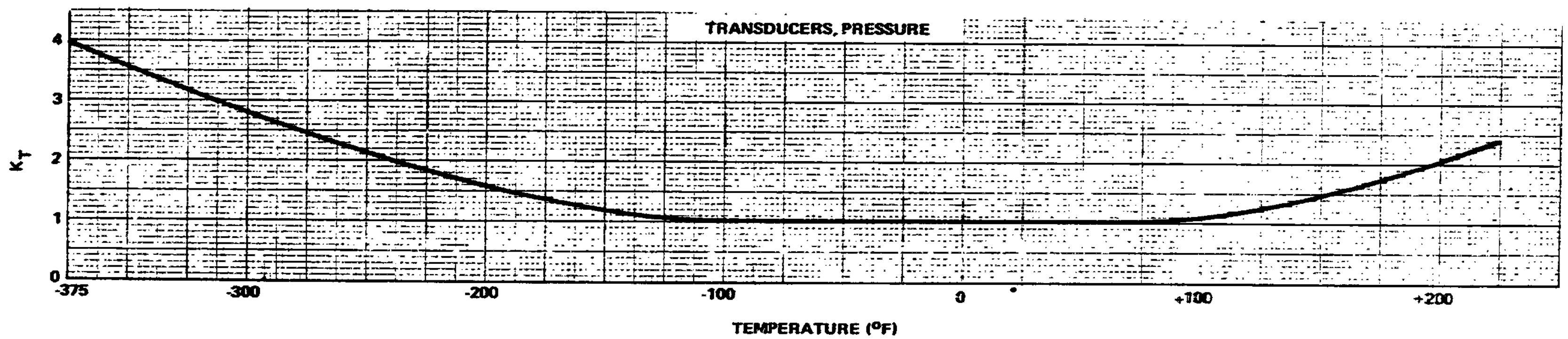

Figure 17. Pressure transducer failure rate adjustment factor (K_T) for temperature.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Temperature Transducers

I. Failure Mode Frequency Ratios (α): 1

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}}.$$

Failure Mode	Alpha Factor (α)
Open	0.55
Short	0.18
Erratic	0.16
High Temperature Reading	0.07
Low Temperature Reading	0.04

II. Environmental Adjustment Factors (K): 2

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}}.$$

Figure 18 shows the temperature transducer failure rate adjustment factor (K_T) for temperature, and Figure 19 shows the temperature transducer failure rate adjustment factor (K_V) for random vibration.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): 2

$\lambda_{90\%}$ = 0.000480 failures per hour. 3

1 Based on 350 temperature transducer failures extracted from 25 000 Saturn UCR's.

2 Based on Saturn test data from 53 qualification test reports.

3 Based on 0 failures in 4798 hours of operation in tests at ambient conditions.

NOTE: Approximately 25 percent of the 350 temperature transducer failures extracted from UCR's were caused by human error. A majority of the human errors were due to improper handling, which was manifested as open circuit failures.

Approximately 18 percent of the failures were caused by lack of protective covers on the temperature transducers and/or the use of improper connectors on the metal-sheathed cables.

Approximately 8 percent of the failures were caused by vendor and manufacturing errors.

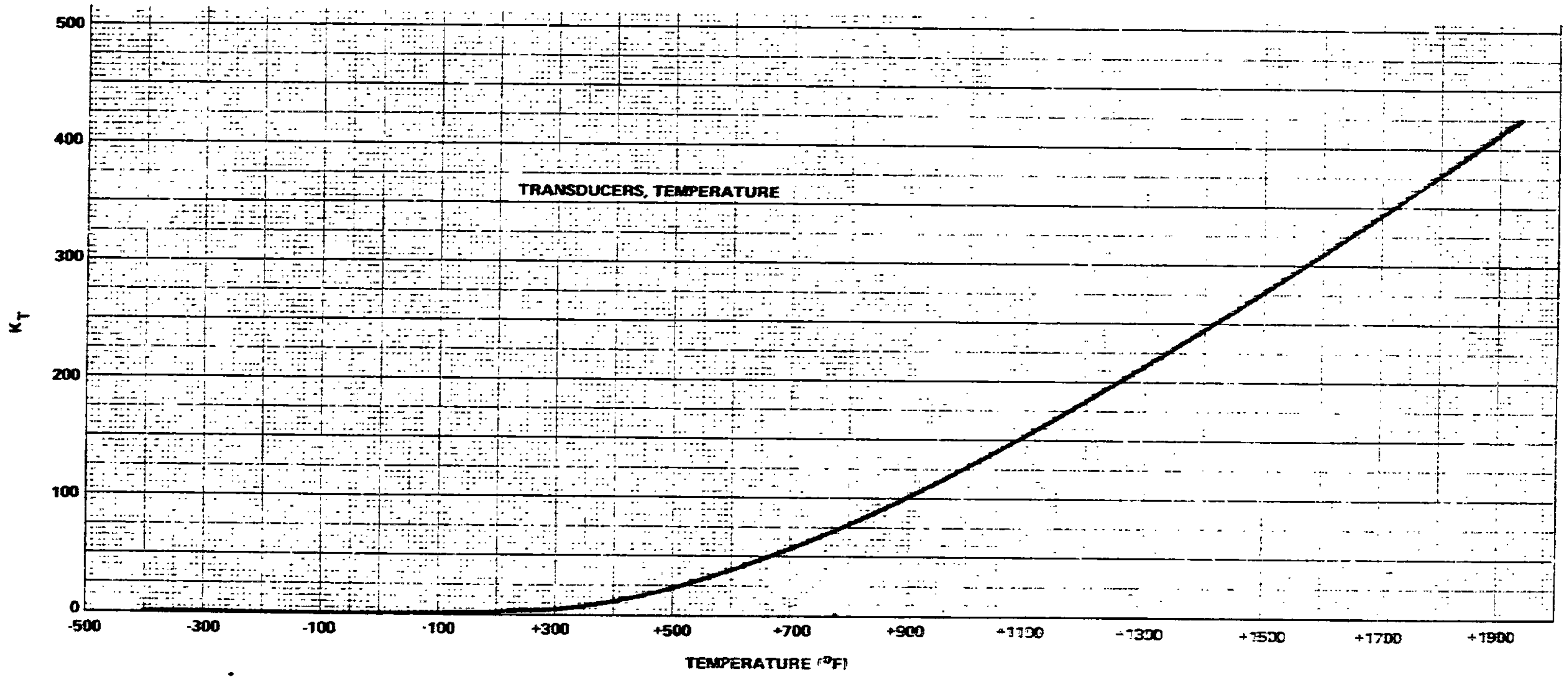

Figure 18. Temperature transducer failure rate adjustment factor (K_T) for temperature.

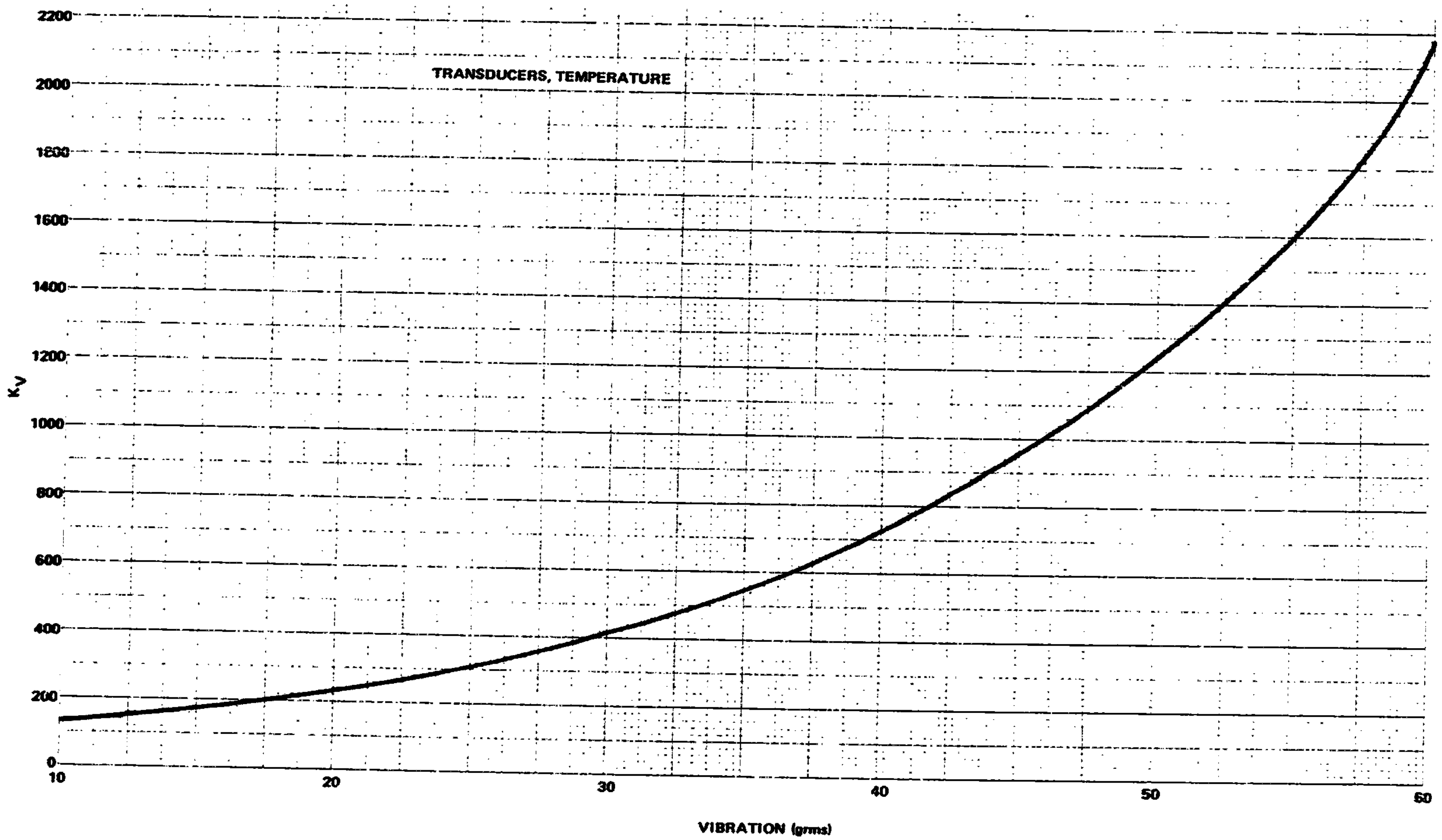

Figure 19. Temperature transducer failure rate adjustment factor (K_V) for random vibration.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Check Valves

I. Failure Mode Frequency Ratios (α): [1]

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}}$$

Failure Mode	Alpha Factor (α)
Failure to Close	0.807
External Leakage	0.067
Failure to Remain Open	0.055
Failure to Open	0.041
Failure to Remain Closed	0.026
Unassigned	0.004

II. Environmental Adjustment Factors (K): [2]

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}}$$

Figure 20 shows the check valve failure rate adjustment factor (K_T) for temperature.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): [2]

$\lambda_{90\%}$ = 0.000021 failures per cycle. [3]

[1] Based on 213 check valve failures extracted from Saturn UCR's and 57 failures extracted from Saturn qualification and reliability test reports.

[2] Based on Saturn test data from 55 qualification and reliability test reports.

[3] Based on 1 failure in 186 495 operational cycles at ambient conditions.

NOTE: Approximately 35 percent of the check valve failures reported on UCR's were caused by (1) rough surfaces on the poppet guide and shaft, (2) galling or peening of the seat and poppet caused by valve chatter, and (3) embrittlement of the poppet seal.

Approximately 22 percent of the check valve failures reported on UCR's were caused by contamination (excessive lubricant, metal particles, corrosion).

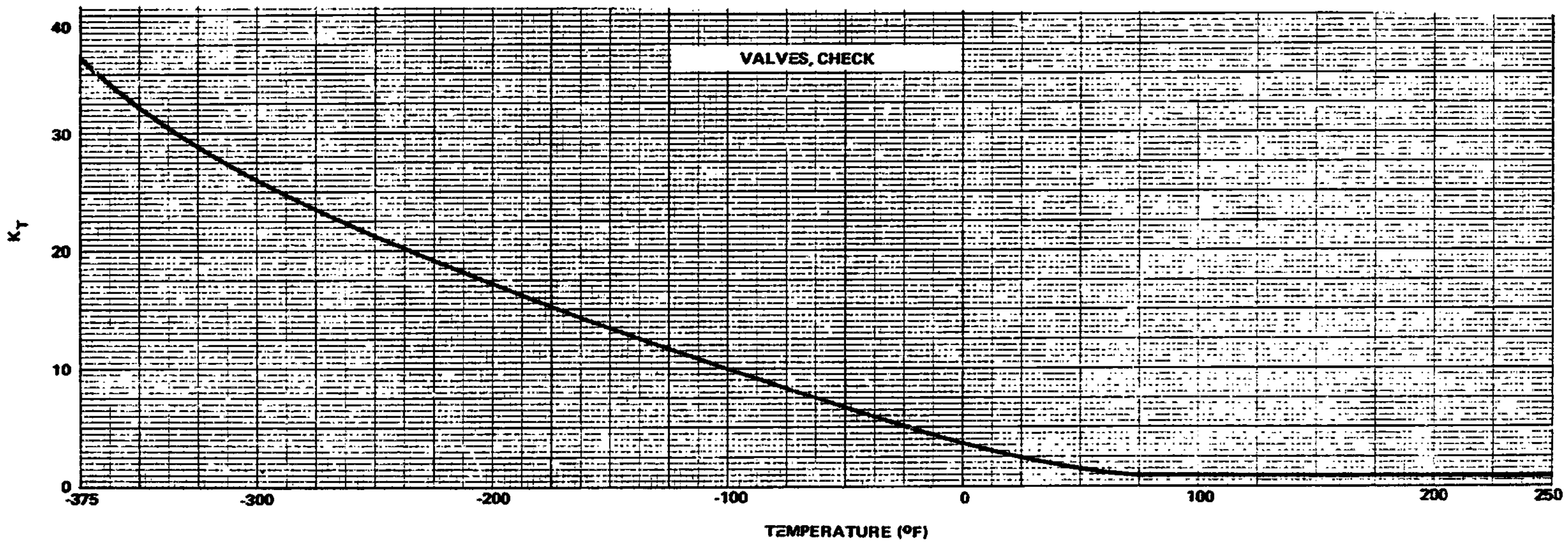

Figure 20. Check valve failure rate adjustment factor (K_T) for temperature.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Shutoff Valves

I. Failure Mode Frequency Ratios (α): [1]

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}} .$$

Failure Mode	Alpha Factor (α)
Failure to Close	0.467
External Leakage	0.172
Position Indicator No Signal	0.145
Position Indicator Erroneous Signal	0.101
Failure to Open	0.075
Failure to Remain Open	0.022
Failure to Remain Closed	0.018

II. Environmental Adjustment Factors (K): [2]

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}} .$$

Figure 21 shows the shutoff valve failure rate adjustment factor (K_T) for temperature and Figure 22 shows the shutoff valve failure rate adjustment factor (K_V) for vibration.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): [2]

$\lambda_{90\%} =$ 0.000033 failures per cycle. [3]

[1] Based on 227 shutoff valve failures extracted from 25 000 Saturn UCR's.

[2] Based on Saturn test data from 62 qualification and reliability test reports.

[3] Based on 7 failures in 353 170 operational cycles in tests at ambient conditions.

NOTE: Twenty percent of the shutoff valve failures reported on UCR's were damage-type failures attributable, in most cases, to human error. The most prevalent causes of the damage-type failures were scratches, nicks, and gouges on the valve flanges.

Approximately 12 percent of the shutoff valve failures reported on UCR's were caused by contamination such as metallic particles, corrosion, moisture, etc.

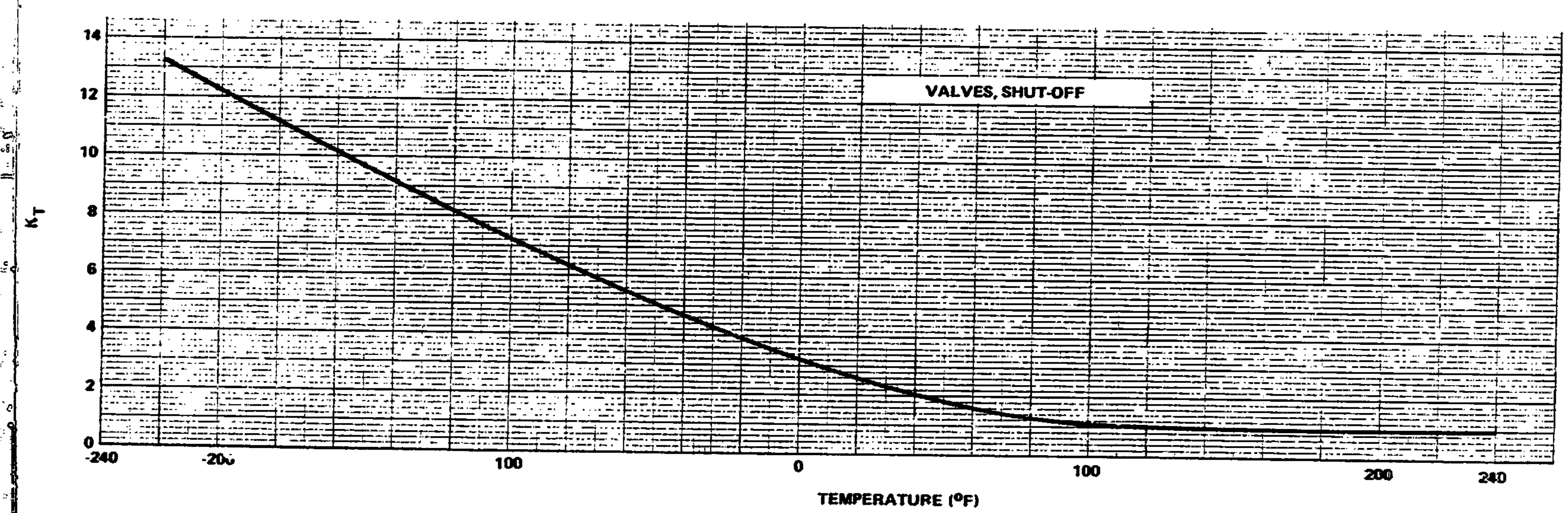

Figure 21. Shutoff valve failure rate adjustment factor (K_T) for temperature.

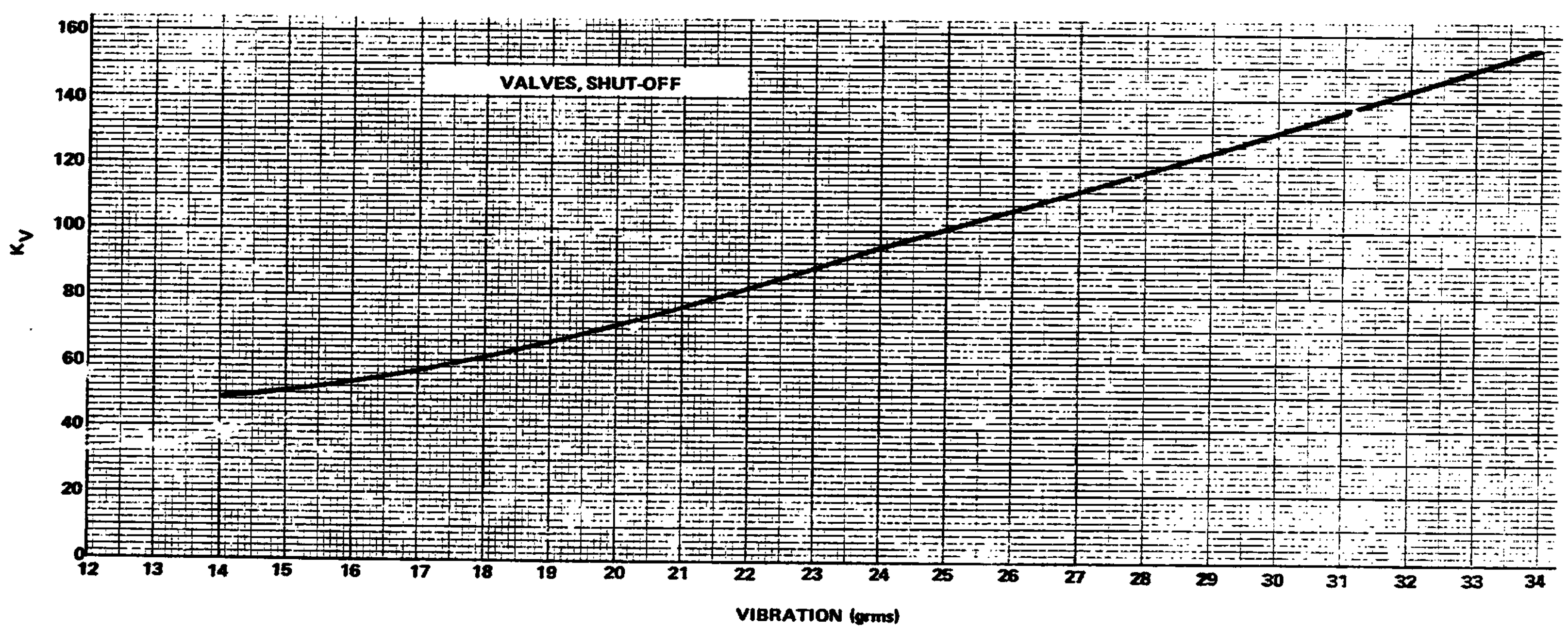

Figure 22. Shutoff valve failure rate adjustment factor (K_V) for random vibration.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Solenoid Valves

I. Failure Mode Frequency Ratios (α): [1]

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}}$$

Failure Mode	Alpha Factor (α)
Failure to Close	0.695
External Leakage	0.122
Failure to Open	0.070
Position Indicator Erroneous Signal	0.061
Position Indicator No Signal	0.026
Failure to Remain Closed	0.026

II. Environmental Adjustment Factors (K): [2]

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}}$$

Figure 23 shows the solenoid valve failure rate adjustment factor (K_T) for temperature, and Figure 24 shows the solenoid valve failure rate adjustment factor (K_V) for random vibration.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): [2]

$\lambda_{90\%}$ = 0.000008 failures per cycle [3]

[1] Based on 115 solenoid valve failures extracted from 25 000 Saturn UCR's.

[2] Based on Saturn test data from 65 qualification and reliability test reports.

[3] Based on 5 failures in 1 173 785 operational cycles in tests at ambient conditions.

NOTE: Approximately 25 percent of the solenoid valve failures reported on UCR's were associated with contamination which appeared as corrosion, grease, metal particles, and moisture.

Approximately 21 percent of the solenoid valve failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures were manifested as cracks, nicks, abrasions, and scratches.

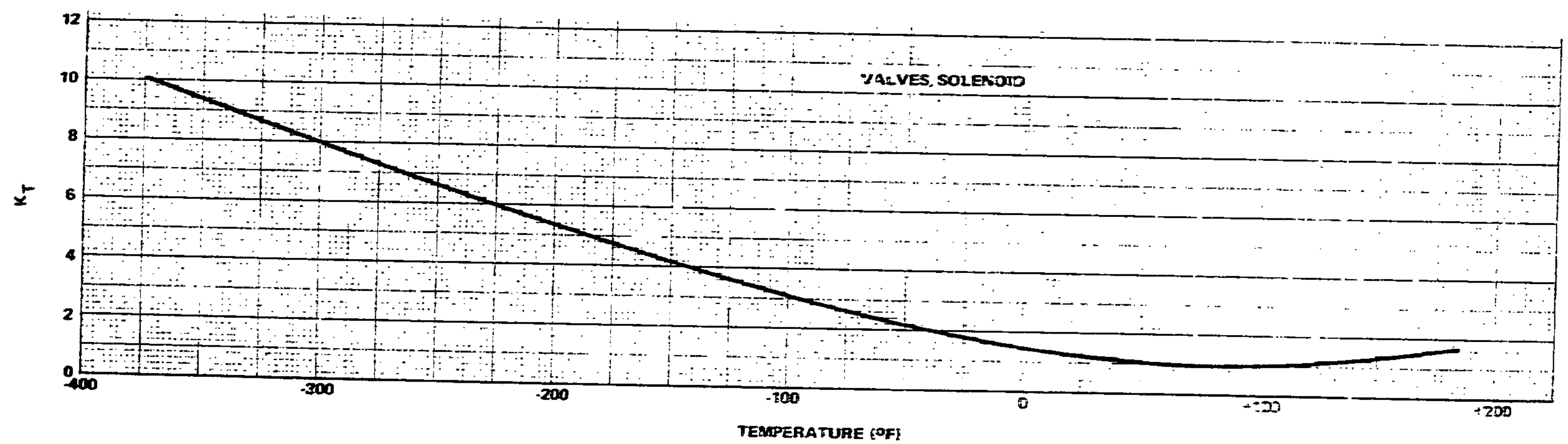

Figure 23. Solenoid valve failure rate adjustment factor (K_T) for temperature.

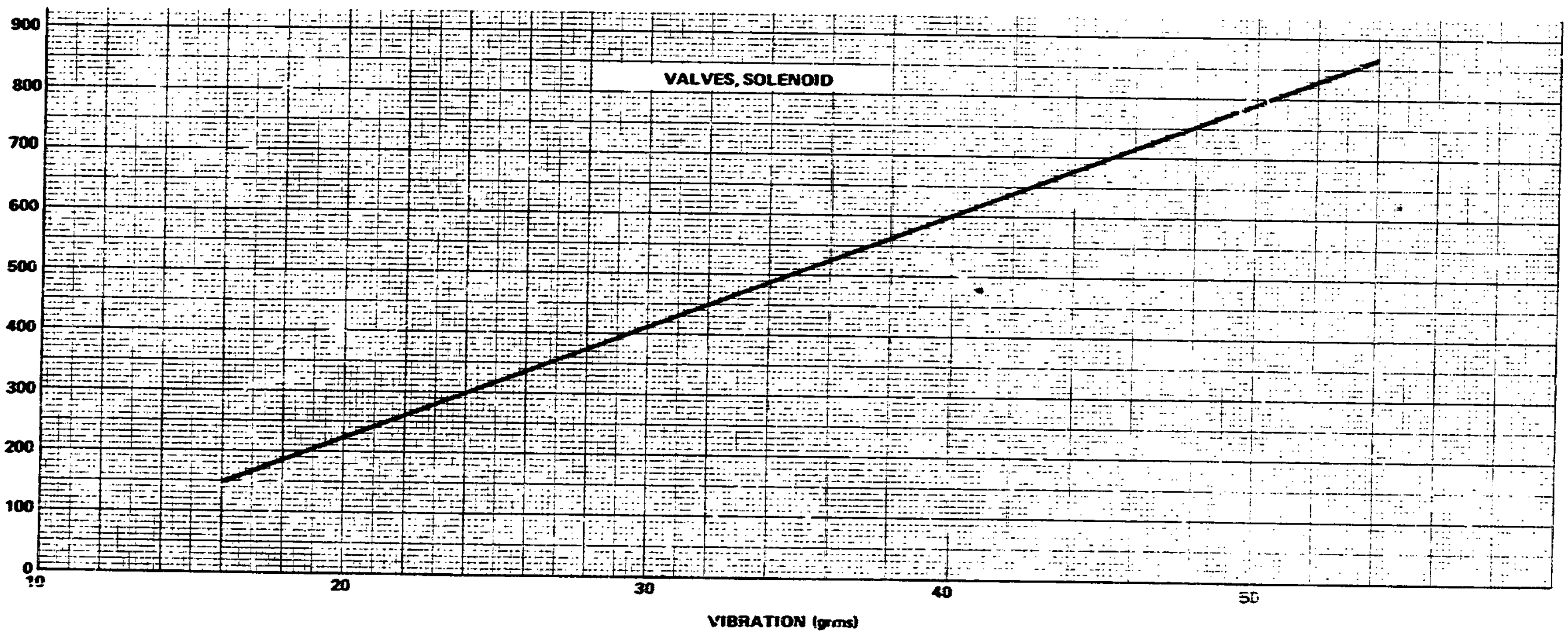

Figure 24. Solenoid valve failure rate adjustment factor (K_V) for random vibration.

Failure Mode Frequency Ratios, Environmental Adjustment Factors, And Failure Rate For Vent And Relief Valves

I. Failure Mode Frequency Ratios (α): [1]

$$\alpha = \frac{\text{No. of failures specific mode}}{\text{Total failures all modes}}$$

Failure Mode	Alpha Factor (α)
Failure to Close	0.531
Position Indicator No Signal	0.156
Failure to Open	0.150
Failure to Remain Closed	0.056
Position Indicator Erroneous Signal	0.050
External Leakage	0.044
Failure to Remain Open	0.013

II. Environmental Adjustment Factors (K): [2]

$$K = \frac{\text{Failure rate at env. level}}{\text{Ambient failure rate}}$$

Figure 25 shows the vent and relief valve failure rate adjustment factor (K_T) for temperature and Figure 26 shows the vent and relief valve failure rate adjustment fact r (K_V) for vibration.

III. Failure Rate at 90-Percent Confidence ($\lambda_{90\%}$): [2]

$\lambda_{90\%}$ = 0.000009 failures per cycle [3]

[1] Based on 160 vent and relief valve failures extracted from 25 000 Saturn UCR's.

[2] Based on Saturn test data from 98 qualification and reliability test reports.

[3] Based on 3 failures in 695 329 operational cycles in tests at ambient conditions.

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NOTE: Approximately 24 percent of the vent and relief valve failures reported on UCR's were associated with contamination which appeared as corrosion, oil, RP-1 fuel, metal particles, and moisture.

Approximately 16 percent of the vent and relief valve failures reported on UCR's were damage-type failures attributable in most cases to human error. The damage-type failures were manifested as gouges, nicks, abrasions, and scratches.

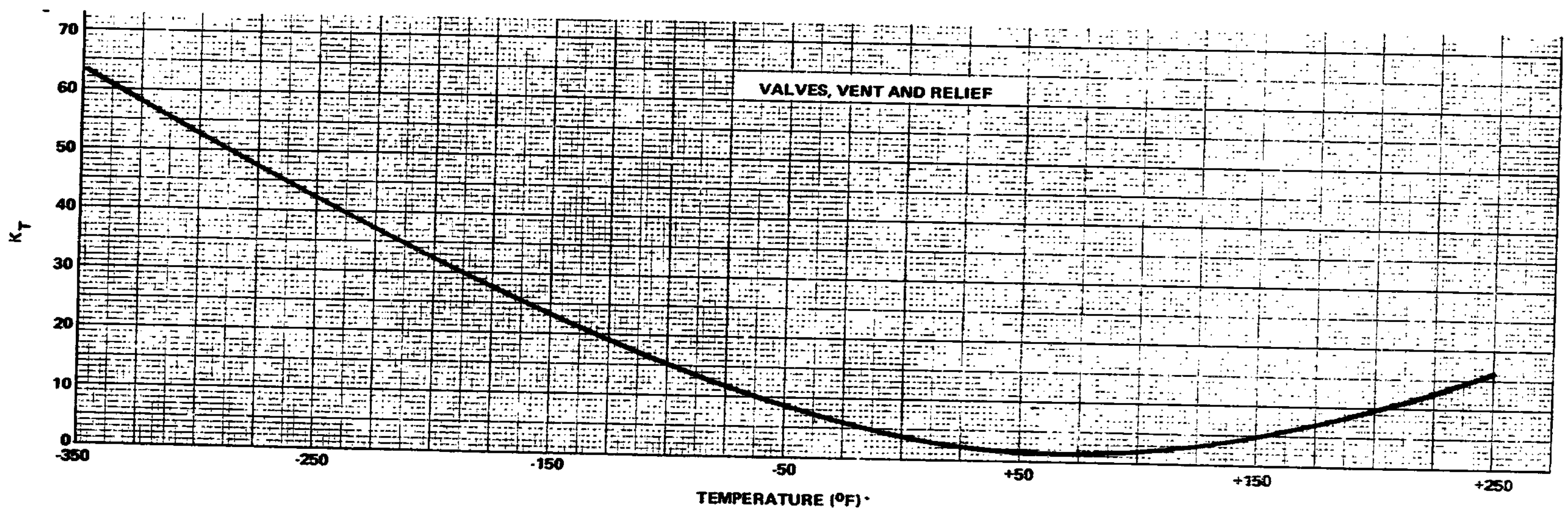

Figure 25. Vent and relief valve failure rate adjustment factor (K_T) for temperature.

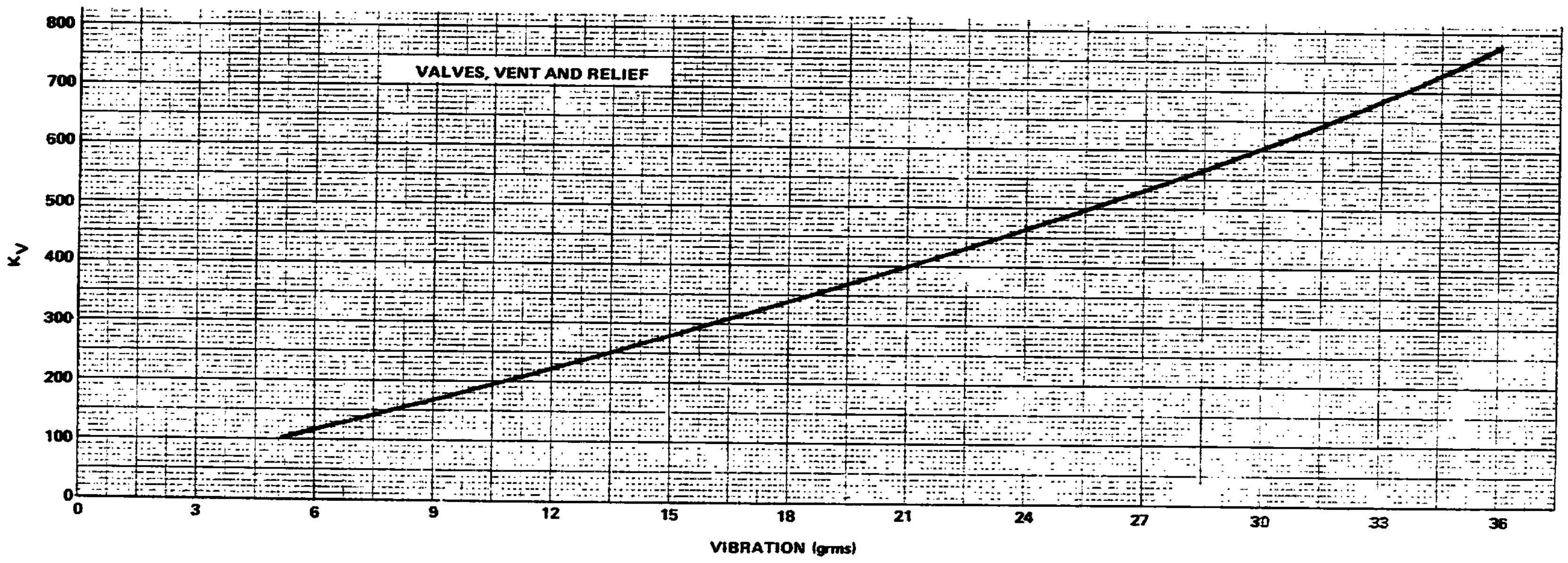

Figure 26. Vent and relief valve failure rate adjustment factor (K_V) for random vibration.

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APPROVAL

SATURN COMPONENT FAILURE RATES AND FAILURE RATE MODIFIERS

By Quality and Reliability Engineering Evaluation Branch
Quality and Reliability Engineering Division
Quality and Reliability Assurance Laboratory

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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